1. Introduction and Aggregate Results

While projections of carbon dioxide (CO_2) emissions from energy consumption are widely available, this information has been lacking for the other (non-CO_2) greenhouse gases (GHGs). The aim of this report is to fill this gap by presenting emissions and baseline projections of the non-CO_2 gases from major anthropogenic sources for all developed countries. This report provides a consistent and comprehensive estimate of non-CO_2 greenhouse gases that can be used to understand national contributions to climate change, mitigation opportunities and costs, and progress under the United Nations Framework Convention on Climate Change (UNFCCC).

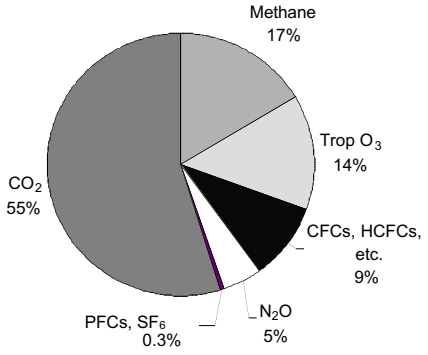
The gases included in this report are the direct greenhouse gases reported by parties to the UNFCCC: methane (CH_4), nitrous oxide (N_2O), and the high global warming potential (high GWP) gases. Historical estimates are reported for 1990 and 1995, and projections of emissions in the absence of climate measures ("Business As Usual") are provided for 2000, 2005, and 2010. Historical and future trends are shown by region and by gas. The emission estimates presented in this report are derived from publicly available country-submitted estimates, when they are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997). In specific cases, the U.S. Environmental Protection Agency (EPA) has revised the national estimates and calculated estimates where they are unavailable from country-submitted reports. Any revisions are intended to ensure overall consistency in approach, because in some cases the available estimates could not be compared to other data in their original form. These revisions and recalculations do not suggest that the country level data are inaccurate. All changes and modifications to national data have been documented.

1.1 Overview of Non-CO_2 Greenhouse Gas Emissions

Each non-CO_2 greenhouse gas is more effective at trapping heat than CO_2. As a result, emissions of these gases contribute significantly to climate change. As shown in Exhibit 1-1, global emissions of methane, nitrous oxide, and all of the high GWP gases (including Montreal Protocol Gases such as CFCs and HFCs, which are not addressed by the UNFCCC) account for approximately 30 percent of the enhanced greenhouse effect since pre-industrial times. In 1990, the non-CO_2 greenhouse gas emissions among the developed countries were 3,573 million metric tons of carbon dioxide equivalent ($MMTCO_2$).

A comprehensive multi-gas mitigation strategy can be less expensive and more effective in mitigating climate change than focusing on only CO_2. In 1999, researchers with the Massachusetts Institute of Technology demonstrated that the "inclusion of sinks and abatement opportunities from gases other than CO_2 could reduce the [global] cost of meeting the Kyoto Protocol by 60 percent" (Reilly et al., 1999a). Additionally, a recent National Academy of Sciences article by NASA scientists concludes that the climate forcing of direct and indirect non-CO_2 greenhouse gases equals that of CO_2 and, at this current forcing level, has contributed to at least 0.5 degrees of future temperature increase (PNAS, 2000). The anticipated

Exhibit 1-1: Contribution of Anthropogenic Emissions of all Greenhouse Gases to the Enhanced Greenhouse Effect Since Industrial Times (measured in Watts/m^2)



Source: IPCC, 1996

future temperature increase is sensitive to atmospheric lifetimes of these gases. For example, methane remains in the atmosphere for approximately 8 to 12 years compared to 50 to 200 years for carbon dioxide (IPCC, 1996). If methane emissions were significantly reduced today, the complete effect on atmospheric concentrations could be seen within a decade, much more quickly than similar reductions in CO_2 emissions. Conversely, the longer lived non-CO_2 gases such as sulfur hexafluoride (SF_6) should be considered as well since any emissions of these gases will continue to affect the atmosphere for at least several hundred years.

1.2 Emission Sources

This report focuses exclusively on anthropogenic sources of the non-CO_2 direct greenhouse gases not covered by the Montreal Protocol. The emissions are converted to a CO_2 equivalent basis using the global warming potentials shown in Exhibit 1-2, as published by the IPCC and recognized by the UN Framework Convention on Climate Change. Exhibit 1-3 lists the source categories discussed in this report. All anthropogenic sources of methane are included, with the major sources considered individually. The major sources of nitrous oxide emissions are presented: agricultural soils, industrial processes, combustion, and manure management. The high GWP sources include substitutes for ozone depleting substances (ODS) and industrial sources of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). More detailed information on each gas and source can be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 through 1999* (EPA, 2001) and *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997).

Exhibit 1-2: Global Warming Potentials

Gas	GWP
Carbon Dioxide (CO_2)	1
Methane	21
Nitrous Oxide (N_20)	310
HFC-23	11,700
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Exhibit 1-3: Sources Included

Gas	Source
Methane	Landfills
	Coal Mining
	Natural Gas
	Oil Systems
	Livestock Manure Management
	Livestock Enteric Fermentation
	Wastewater Treatment
	Other Agriculture:
	• Rice Cultivation
	• Agricultural Residue Burning
	• Prescribed Burning of Savannah
	Other Non-Agriculture:
	• Fuel Combustion
	• Industrial Processes
	Waste Incineration
Nitrous Oxide	Fossil Fuel Combustion
	Industrial Processes
	Agricultural Soils
	Livestock Manure Management
High GWP Gases	
HFCs, PFCs	Substitute for Ozone-Depleting Substances
HFC-23	HCFC-22 Production
PFCs	Aluminum Production
SF_6	Magnesium Production
	Electrical
PFCs, SF_6	Semiconductor Manufacturing

1.3 Approach

The analysis provides estimates for 38 developed countries for 1990, 1995, 2000, 2005, and 2010. In addition to the individual country data, EPA presents overall trends by region and by gas. The regional groupings include the 15 countries of the European Union (EU-15), other western European countries, Eastern Europe, and Australia/New Zealand. These

Exhibit 1-4: Definition of Regional Country Groupings

EU-15: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom

Other Western: Iceland, Liechtenstein, Monaco, Norway, Switzerland

Eastern Europe: Bulgaria, Croatia, Czech Republic, Estonia Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, Ukraine

regional country groupings are further defined in Exhibit 1-4.

The emission estimates for methane, nitrous oxide, and the high GWP gases are described in Chapters 2 through 4, respectively. Chapter 5 describes in detail the methodologies used to compile the historical and projected emissions. In general, estimates were developed as follows:

- For all methane sources and the industrial sources of nitrous oxide, the primary sources of data on historical and projected emissions are National Communications and annual inventories submitted by Parties to the UNFCCC.
- For the remaining nitrous oxide sources, for many countries EPA adjusted the estimates because many Second National Communications did not use the *Revised 1996 IPCC Guidelines*. The use of these new methods for agricultural nitrous is important because the methods have improved significantly. For 1990 and 1995 historical inventories, EPA used recent annual inventories submitted to the UNFCCC, if consistent with the IPCC guidelines. The projections for 2000 to 2010 are based upon internationally recognized data sets to compute projections consistent with the *Revised 1996 IPCC Guidelines*.
- Most countries did not include detailed estimates for high GWP emissions and projections in their Second National Communications. Where estimates are available from national sources, they have been used. Otherwise, this analysis developed emission estimates for the high GWP source categories not covered by the Montreal Protocol.

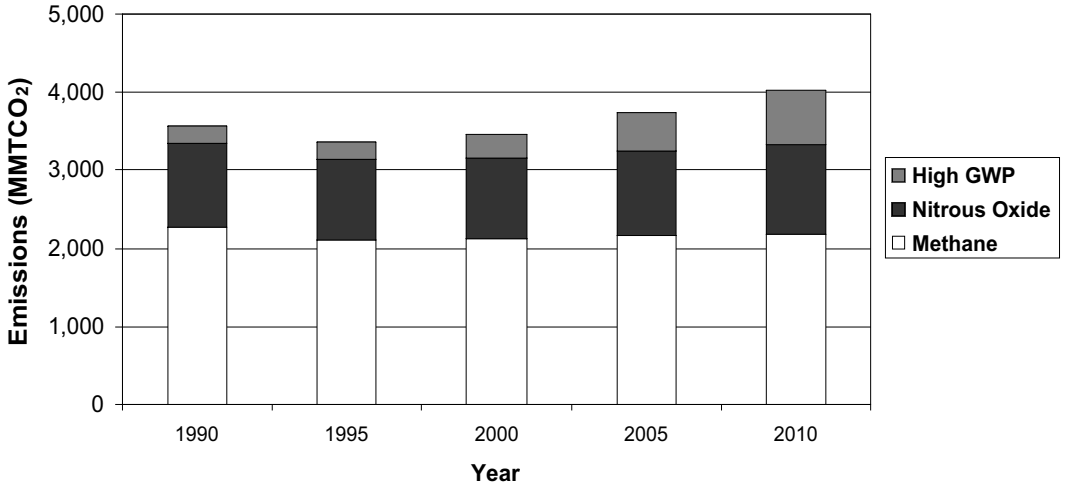
The projections in this report provide a consistent baseline to compare opportunities and costs of mitigation options across countries. In some cases, national projections were adjusted in order to remove the effects of climate policies. This step was necessary to ensure that assessments of the applicability of various mitigation options to particular sources were done on a consistent basis – in this case, one that assumed no climate policies. For this reason, actual emissions over time are likely to be lower than these business as usual (BAU) forecasts because many businesses and governments plan to implement additional actions to reduce emissions.

1.4 Summary Estimates

In the "Business as Usual" scenario, emissions in developed countries are projected to be 4,009 million metric tons of CO_2 equivalent ($MMTCO_2$) in 2010, an increase in emissions of approximately 12 percent from 1990. Emissions declined from 1990 to 1995 but will increase from 1995 through 2010. As Exhibit 1-5 shows, while methane and nitrous oxide emissions drop slightly in the middle of the period, they are generally expected to recover to the 1990 levels by 2010. High GWP gas emissions, although small in 1990, are projected to triple over the period, as new chemicals are deployed as substitutes for the ozone depleting substances being phased out under the Montreal Protocol.

There are three main driving forces for the non-CO_2 GHG trends in the developed countries. First, the economic transitions of several countries during the early 1990s, in particular, resulted in an emissions decline for methane and nitrous oxide. Since 1995, however, emissions have been increasing as the

Exhibit 1-5: Evolution of Non-CO2 GHG Emissions 1990 through 2010 ($MMTCO_2$)



economies recover. Secondly, the coal industry is undergoing restructuring in a number of countries, resulting in a sustained decrease in methane emissions. Third, there will continue to be growth in emissions of high GWP gases due to the phase out of Ozone Depleting Substances and strong predicted growth in other industrial applications.

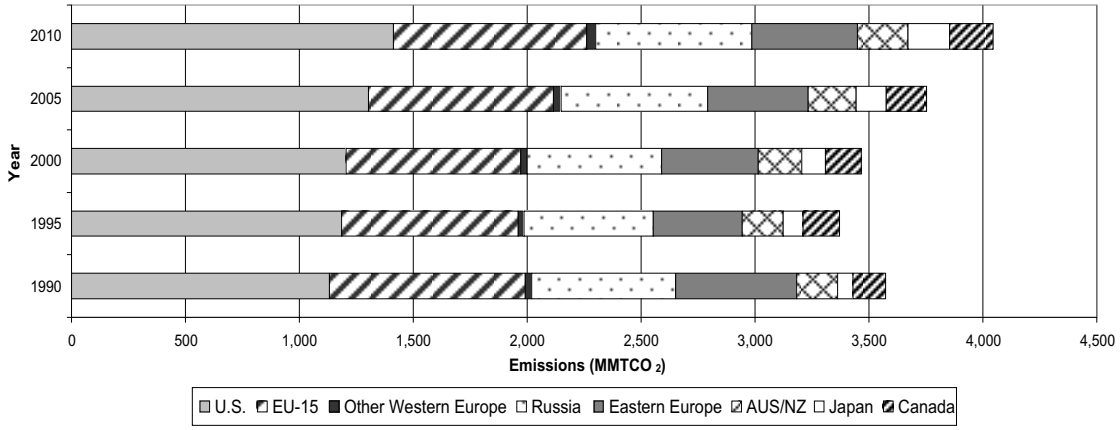
In the early 1990s, Eastern Europe and the countries of the Former Soviet Union began a rapid transformation to market economies that led to an economic downturn in many sectors, particularly agriculture and livestock. According to the most recent projections submitted in National Communications to the UNFCCC, these countries expected their economic recovery to be well underway by 2000, explaining the fall and subsequent rise in projected emissions. Based on actual experience, however, these projections may be overstated. In many cases the economies are not recovering as quickly as expected.

Additional restructuring occurred in the coal sectors of transitioning countries (EITs) as well as in other European countries. Many European countries have closed most of their gassiest underground mines, thereby reducing methane emissions significantly. Unlike the other sectors, emissions are not expected to increase as quickly since many of the mines will remain closed for the foreseeable future due to the removal of subsidies and continuation of unfavorable market conditions.

Despite the impact of major economic and sector restructuring, in the absence of climate mitigation policies, total methane emissions are projected to recover to 1990 levels by 2010. This increase is due to the expected economic recovery in EITs, and high industrial and agricultural growth in other regions. The growth in emissions is lessened somewhat by significant efforts to manage methane emissions in the waste sector. As many developed countries increasingly rely on landfills, they are also improving waste management practices, resulting in a relatively stable emission rate in spite of overall economic and population growth.

As shown in Exhibit 1-5, nitrous oxide emissions decreased only slightly between 1990 and 1995 despite the economic restructuring in several countries. Large agricultural countries with growing economies such as the U.S. and EU-15 offset the emission reductions experienced by others. However, another significant change is occurring as the second largest source of emissions shifts from industrial processes to mobile sources. In 1990, industrial processes accounted for about 15 percent of total emissions. However, these emissions drop

Exhibit 1-6: Regional Non-CO_2 GHG Emissions and Projections 1990 through 2010 ($MMTCO_2$)



dramatically from 1990 to 2000 and are expected to stay near 2000 levels out to 2010. Total N_2O emissions remain level because of the dramatic increase in mobile source emissions.

Unlike methane and nitrous oxide, emissions of high GWP gases are expected to grow significantly over the period due to the phase out of Ozone Depleting Substances (ODS) under the Montreal Protocol, and strong predicted growth in other applications such as semiconductors. As ODSs are phased out in developed countries, other gases, including HFCs and PFCs, are substituted. The rate of growth is uncertain, however, because the choice of chemicals and potential new technologies or operating procedures could eliminate or decrease the need for these gases. In the BAU case the increase in these sectors offsets an overall reduction in methane. As noted earlier, these projections do not include climate initiatives such as the semiconductor industry's voluntary reduction plan, which is expected to reduce emissions substantially from this sector.

From 1990 to 2010, emissions of non-CO_2 greenhouse gases increase in every region except Eastern Europe, as Exhibit 1-6 illustrates. U.S. emissions are projected to increase by 210 $MMTCO_2$ over this period, the largest absolute increase and a percentage increase of over 200 percent**.** EU-15 is next with an increase of 107 $MMTCO_2$. Japan, Russia, and Canada project increases of 74, 32, and 13 $MMTCO_2$, respectively.

1.5 Limitations

Although this report includes the latest historical data available, such data are not available for the year 2000. For a given time series, a national inventory is not due to the UNFCCC for almost a year and a half after that year (i.e., 2000 inventories are due in April 2002). As this information becomes available, it will be incorporated in updated publications of this report.

While the latest available information is reflected in these estimates, the projections are sensitive to changes in key assumptions. For example, the emissions rates of new equipment using the ODS substitutes are likely to be much lower than the leakage rates of the older equipment. This newer equipment is only now being phased in, and the long-term emissions characteristics are not yet well known.

Additionally, in some cases the "business as usual" baseline includes incidental greenhouse gas reductions originating from climate related actions or government polices. For consistency, EPA deducted the effects of planned mitigation efforts, using methods based on US technologies. The assumptions may not hold true for all countries to which it was applied. Alternative definitions of "business as

usual" activities could lead to different estimates for some sources.

Finally, data gaps existed in emissions data for several countries. To fill the gaps, EPA used methods ranging from interpolation to growth patterns based on analogous countries. The appendices detail all adjustments for each country and source.

1.6 Organization of This Report

The remainder of this report expands upon these results in four main sections. Emission inventories and projections by country and region are presented in Chapter 2 for methane, Chapter 3 for nitrous oxide, and in Chapter 4 for high GWP gases. Within each of these chapters, the discussion covers all key sources that contribute to emissions. Chapter 5 presents the methodology used to gather the most recent emissions inventory and projection data, and the data sources and methods used to adjust the available data where necessary in order to make the overall estimates internally consistent and comparable. Documentation of individual data points is provided in the appendices.